Sveriges lantbruksuniversitet
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Department of Soil and Environment

Nutrient concentrations before and after the Focus on Phosphorus project in E23 catchment

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Abstract

Between 2007-2014, as part of the Greppa Näringen, there was a subproject on phosphorus losses called Focus on Phosphorus (*FoP*; Greppa Fosforn). Previous measures on eutrophication mainly focused on nitrogen leakage, whilst the purpose of *FoP* was to test already known mitigation methods against phosphorus losses in the field. The aim of this study is to evaluate the impact of the measures in one of the three pilot areas in *FoP*, catchment E23 in Östergötland. The three main measures implemented during the project were: structure liming, construction of a two-stage ditch and a sedimentation pond along with modernising the drainage in the entire catchment.

Several hydrochemical parameters (Total Phosphorus, TP, Phosphate Phosphorus, PO_4-P, Particulate Phosphorus, PP, Total Nitrogen, TN, Nitrate Nitrogen, NO_3-N, Ammonium Nitrogen, NH_4-N, Total Organic Carbon, TOC and Total Suspended Solids, TSS) were studied with both flow proportional and manual measurements. Discharge, temperature, precipitation and run off data were obtained from the Swedish Meteorological and Hydrological Institute (SMHI).

The flow proportional, compared to the manual measurements showed higher concentrations of all parameters except NH_4-N and TOC. In both flow proportional and manual measurements, the concentrations of TP and PP are lower after *FoP* whereas the concentrations of TN, and especially NO_3-N have increased. TOC is significantly lower after the project. In addition to the flow proportional and manual sampling, the synoptic measurements also showed that the concentrations of TP are lower in all sampling points along the main stream. Moreover, a distinct increase of NO_3-N in all sampling points can be observed. The monthly mean temperature was slightly higher after *FoP*, while precipitation, run off and discharge were slightly lower after *FoP*. With a lower discharge after *FoP*, nutrient concentrations would have been slightly lower even without measures. The results show that selection of measurement method can affect the evaluation of the effectiveness of the mitigation measures. The measurement methods all have pros and cons and to achieve any viable conclusions, measurements must span a long period of time. The analysis shows an unexpected increase in N concentrations. Hence, further work needs to be done to establish whether there is any correlation between P reduction and N increase.

Keywords: phosphorus, Greppa fosforn, two-stage ditch, structure liming, sedimentation pond

Sammanfattning

Som ett delprojekt inom Greppa näringen pågick 2007–2014 projektet Greppa fosforn. Tidigare åtgärder mot eutrofiering har främst fokuserats på kväveläckage medan Greppa fosforns syfte var att testa fosforreducerande åtgärder praktiskt i fält. Denna rapports syfte är att utvärdera åtgärdernas effekt i ett av de tre pilotområdena, avrinningsområde E23 i Östergötland. De tre huvudsakliga åtgärderna som genomfördes under projektet var strukturkalkning samt anläggning av ett tvåstegsdike och en fosfordamm.

Ett antal hydrokemiska parametrar (totalfosfor, TP, fosfatfosfor, PO_4-P, partikulärfosfor, PP, totalkväve, TN, nitratkväve NO_3-N, ammoniumkväve, NH_4-N, totalt organiskt kol, TOC och suspenderat material, TSS) studerades i både flödesproportionella- och manuella mätserier. Synoptisk data analyserades från de år då mätningar genomfördes. Vattenflöde, temperatur-, nederbörd- och avrinningsdata hämtades från SMHI.

Den flödesproportionella mätserien, jämfört med den manuella, uppvisar högre koncentrationer för alla parametrar förutom NH_4-N och TOC. I de båda långtidsserierna är koncentrationen av TP och PP lägre efter FoP medan koncentrationen av TN, och framförallt NO_3-N har ökat. TOC är betydligt lägre efter projektet. Den synoptiska mätserien består av betydligt mindre data än långtidsserierna men TP är lägre i alla punkter och en tydlig ökning av NO_3-N i alla punkter kan urskiljas. Temperaturen var något högre efter FoP medan nederbörd, avrinning och vattenflödet var lägre efter projektets avslut. Med ett lägre vattenflöde efter projektet torde näringskoncentrationerna, även utan åtgärder, vara något lägre. Resultatet indikerar att val av mätmetod uppvisar något olika samband. Mätmetoderna har alla för- och nackdelar. Intressant är ökningen av N vilket går emot projektets syfte om en minskad eutrofiering. Detta är viktig fråga för framtida studier.

Nyckelord: fosfor, Greppa fosforn, tvåstegsdike, strukturkalkning, fosfordamm

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Abbreviations

FoP	Focus on Phosphorus
TP	Total Phosphorus
PP	Particulate Phosphorus
PO_4-P	Phosphate Phosphorus
TN	Total Nitrogen
NO_3-N	Nitrate Nitrogen
NH_4-N	Ammonium Nitrogen
TSS	Total Suspended Solids
TOC	Total Organic Carbon

1 Introduction

1.1 Background

Eutrophication is an environmental problem and affects the whole ecosystem. Agriculture is responsible for a significant part of the nutrient leakage to the sea but the food production is essential and cannot be phased out. A sustained production is therefore desirable and implementation of mitigation measures against the nutrient and sediment losses needed to reduce eutrophication. Previous efforts have focused on reducing nitrogen (N) leakage to the sea (Naturvårdsverket, 2009a). In the campaign plan for the marine environment in 2006, the Swedish Environmental Protection Agency suggested measures also against P-losses (Naturvårdsverket, 2009a). A lot of work has been done to mitigate eutrophication in Sweden and one of them is a project called Focus on Phosphorus (*FoP*). It was a pilot project in Greppa Näringen during 2007-2014. The aim of the project was to test practically already known mitigations methods and evaluate them in the field. Three different catchments were selected in the programme: N33 in Halland, E23 in Östergötland and U8 in Västmanland. They are all agricultural regions with intensive farming and high losses of phosphorus (Malgeryd m.fl., 2010).

Several mitigations measures have been implemented during the project, including structure liming, construction of a two-stage ditch and a sedimentation pond and this study will focus on these measures. In addition, other mitigations methods have been done as extension service, adapted phosphorus fertilization, buffer zones, improved drainage and cutting of the vegetation in the main ditch. They have all been done in the first period 2006-2009 of the *FoP* project (Malgeryd m.fl., 2010).

The aim of this study was to evaluate if the measures in E23 catchment have had a positive effect on water quality in the main stream draining the catchment.

This thesis includes description of the objectives and implementation of the *FoP* project in E23, statistical analysis of hydrochemical data and evaluation of meteorological parameters and flow data.

The main questions of this work are:

- How has the water quality changed, since completion of the FoP project in E23?
- What impact have had weather conditions on measures effectiveness?

2 Theory

2.1 Eutrophication

Eutrophication is caused by excess concentrations of nutrients, mainly N and P, in both land and water. The eutrophication problem is widespread, especially in the Baltic Sea basin and the southern parts of Sweden. The sources of pollution contributing to eutrophication include private sewers, treatment plant and leaching from arable land (Naturvårdsverket, 2009a).

In 2006 the Baltic Sea received 121 000 tons of N and 3550 tons of P from soils and human activity in Sweden. Half of it came from natural leaching from forest and arable soils. Of the human emissions, 40% of both N and P come from the agriculture, while 37% of N and 54% of P come from point sources such as industries, treatment plants and private sewers (Kling, 2006). As the food production is necessary and cannot be reduced, the only option to reduce eutrophication is to implement mitigation measures.

Phosphorus losses from agriculture vary between 0,03-1,5 kg ha^{-1} and the mean value is 0,4 kg ha^{-1}. Around 90% of the losses happens during only 10% of the time from 1% of the fields (Johannesson and Kynkäänniemi, 2012). General recommendations are therefore not helpful and field by field solutions need to be implemented. Soil type, animal production, vegetation and other local conditions must be considered. Leakage of N is more distributed over the whole agriculture landscape, but is especially problematic in areas with more sandy soils (Eriksson et al., 2011).

One of the national environmental objectives in Sweden, Zero Eutrophication is focused on reducing excess N and P to streams and lakes. The environmental quality objectives describe the current state of the environment and the final goal with the objective. The objectives also include specifications and indicators used for the follow-up. The aim with the Zero Eutrophication is to achieve nutrient concentrations without any negative impact on human health, biological diversity or the possibility of varied use of land and water. In practise, this means significantly reducing the amount of N and P entering aquatic ecosystems (Swedish Environmental Protection Agency, 2017).

2.2 Mitigation measures

2.2.1 Mitigation measures in E23 catchment

Table 1 shows an overview of the main mitigation measures and where in the catchment they were built. Total area of the catchment is 728 ha where 55% is arable land. The measures function and construction are explained below.

Table 1. Measures' location and year of implementation in E23

Measure	**Years**	**Sampling points**	**Area ha**	**% area of the catchment**
Structure liming	2010–2011	12, 14,44, 55, 60, 63, 67	223.0	31
Lime-filter ditches	2012–2013	63, 44, 18, 11, 12	50.3	7
Two-stage ditch	Spring 2014-autumn 2014	Between 53–60	0.7	
Sedimentation pond	2014	Before 60	0.15	

2.2.2 Two-stage ditch

Ditches in the agricultural landscape drain soil to enable effective farming. The water level must be kept low enough for plant roots so they are not flooded and deprived of oxygen and to reach a stability of the soil enough for heavy machines. In heavy rain, the ditches should also carry away excess water (Vattenenheten, Jordbruksverket, 2013).

Traditional ditches can cause some problems despite, being necessary in the agricultural landscape. A bad drainage can contribute to an increased leakage of N and P. Transport of suspended solids to culverts, ponds etc. can cause clogging with negatives effects for aquatic organisms (Mahl et al., 2015).

Traditional, straight ditches reduce the biodiversity and the self-purification capacity and increase the risk of flooding downstream. Usually the ditches are considered to be conveyors for pollutants. Previously, the measures against nutrient losses have been focused on reducing before or after and not during the transport through the ditch (Vattenenheten, Jordbruksverket, 2013).

To build a two-stage ditch with a flood plain on both side of a furrow has never been tested in a large extension in Sweden. Most of the published research has been done in the US at Ohio State University. Their research showed that the natural appearance of a small stream is a tiny furrow surrounded by a flood plain at a slightly higher altitude (Vattenenheten, Jordbruksverket, 2013).

In a two-stage ditch, during higher water flows, water overflows onto the flood plain and enables particles sedimentation. The natural streams are considered to have advantages in terms of stability, reducing erosion and retaining nutrients and biodiversity. The research emphasizes that two-stage ditches are perceived by the farmers as more stable and requiring less maintenance than a traditional ditches (Johannesson and Kynkäänniemi, 2012).

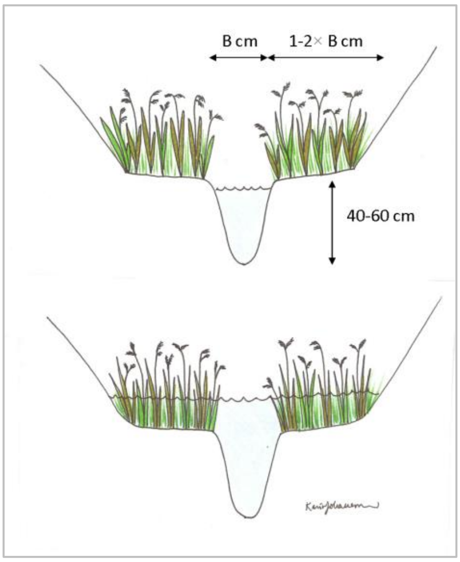

Figure 1. An illustrative picture of an optimal two-stage ditch with a furrow and flood plain on both sides (Jordbruksverket, vattenenheten)

The flood plain should be covered with vegetation which needs to be cut down at least once a year. The terraces can manage high water flows without flooding and more water can stay in the ditch. When the flow stream transports the particles slowly, they can sediment down to the bottom. After some years the ditches need to be dredged out and the material can be reused on the fields. Two-stage ditches can also reduce N with the vegetation nutrient uptake and the denitrification in the sediment (Johannesson and Kynkäänniemi, 2012).

2.2.3 Structure liming

Structure liming is a way to improve and stabilize structure of clay soils by creating more and stronger aggregates, and reducing the soil ability to shrink and swell. During liming of arable land, two different types of lime are typically used. Burned, CaO and slaked, $Ca(OH_2)_2$ lime that contains free lime and is very soluble. The structural effect is quick and visible. The other type is limestone flour, $CaCO_3$ which has a much more limited effect on the structure. The current structure of lime is usually a mixture of both types but it is the burned and slaked one that has the structure formative effect (Berglund and Blomquist, 2015).

In the soil, clay particles are saturated with calcium ions, which makes the base saturation increase rapidly. The base saturation affects the chemical, biological and physical properties in the soil. Bacteria and worms thrive while soil fungi prefer a more acidic environment. The bivalent calcium and magnesium ions flocculate and clay particles clump together to form aggregates (Eriksson et al., 2011). A ratio of 5 tons mixed lime structure per hectare is common on clay loam in Sweden. To have some effects of the liming, the soil needs to be at least a clayey loam. Soils with less clay particles than 25% do not respond well to liming (Wahlberg, 2016).

Another way to use lime against P losses is to construct a lime-filter ditch. During subsoil drainage structure lime is mixed with the soil as using to backfilling. Approximately 7 tons structure lime per hectare is necessary. The lime-filter ditches create a regular infiltration and contribute to a better drainage (Börling et al., 2017)

2.2.4 Sedimentation pond

Wetlands to reduce P losses have another layout than those for N. In Sweden not so many ponds have been constructed in this way and they need to be placed high in the catchment and close to the sinks. The size of the pond is related to the catchment and recommended size is 0,1-0,4 % of the catchment (Johannesson and Kynkäänniemi, 2012). The run-off is another important parameter for the optimal size. The pond should consist of a deeper part closest to the inlet with a size of 20-30% of the ponds area. Here most of the sedimentation should take place. The other part should be after, downstream and covered with wetland vegetation. The vegetation stabilizes the bottom and act as a filter where more sedimentation can take place. To keep the deep of the pond, cleaning with a digger is necessary. The material can be reused on the fields (Johannesson and Kynkäänniemi, 2012).

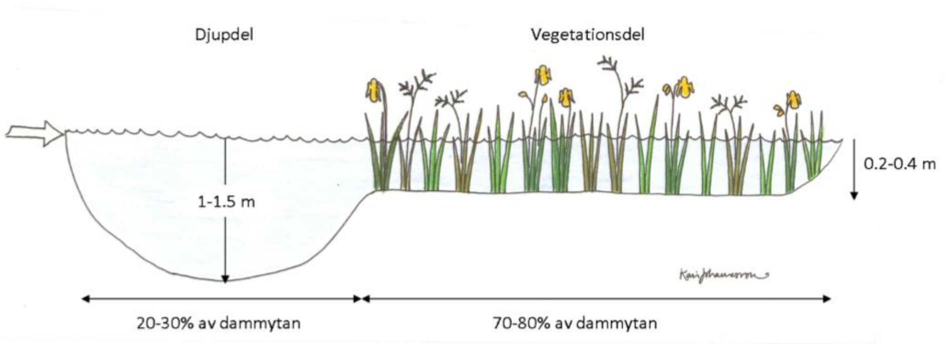

Figure 2. Sedimentation pond design (Jordbruksverket, vattenenheten). The Pond should have a deeper part closest to the inlet were mostly of the sedimentation take place and a second, shallower part covered with vegetation

2.3 Meteorological conditions

The meteorological conditions are important parameters for the water flow but also agricultural practices. At high precipitation, erosion of large particles increases (Vattenenheten, Jordbruksverket, 2013). Runoff is an important parameter especially during snow melt. Variations of the temperature can affect the oxygen solubility in water and thus the solubility of NH_4-N (Ekologgruppen, 2014).

One effect of the climate change is that the temperature and precipitation in Östergötland will increase and an adaption to climate change is needed to take place. Because of more precipitation, discharge will increase as well (Ehrnstén and Länsstyrelsen Östergötland, 2011). This is an expected change in the long-term and the variations in and between years can still be significant.

Figures 4-7 show how different weather parameters varied over time in the catchment E23. Long-term averages were calculated by SMHI over a standardised period of 30 years and the current averages are from 1961-1990 (SMHI, 2018).

As the Figure 4 shows, the temperature almost follows the long-time average. Runoff is normally correlated with snow melting and has a yearly peak in spring. Precipitation normally peaks in summer or early autumn.

Discharge has been measured from 1976 and has therefore not been calculated as a long-time average. Figure 8 shows how discharge varies over time since FoP started.

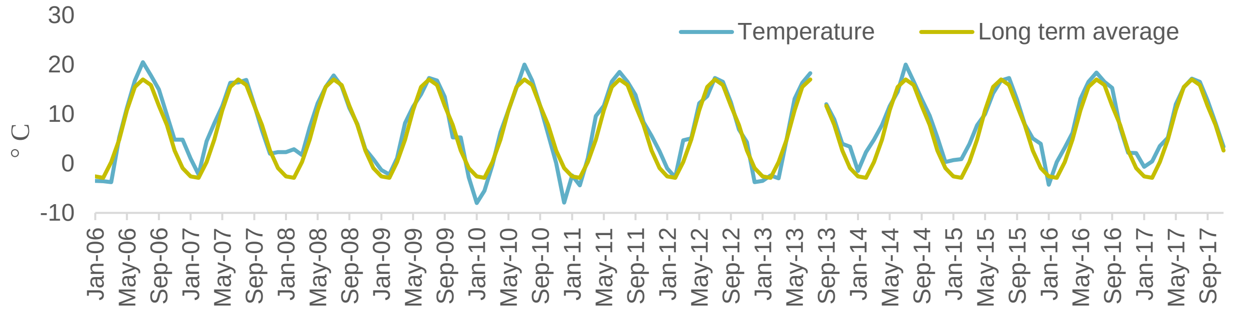

Figure 3. Monthly average temperatures in Norrköping 22 km from Ryttarbacken. Long-term values are calculated by SMHI over a standardized 30 years period

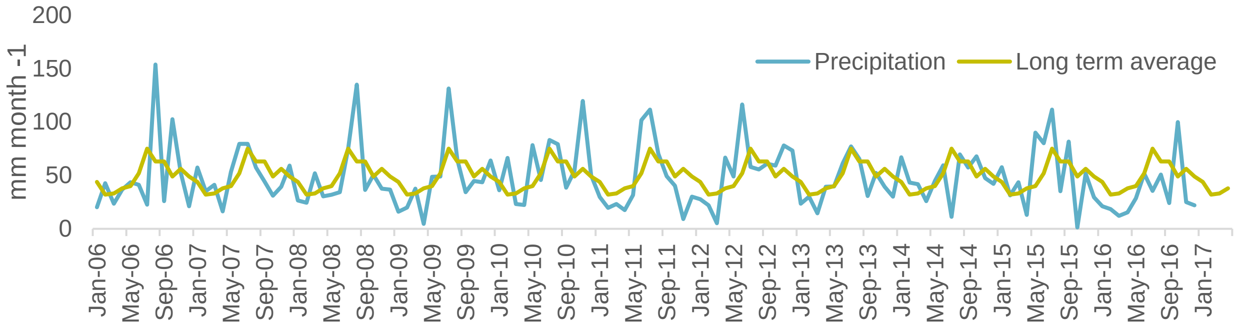

Figure 4. Monthly average precipitation in Söderköping, 21 km from Ryttarbacken 2006-2017. Long-term values are calculated by SMHI over a standardized 30 years period

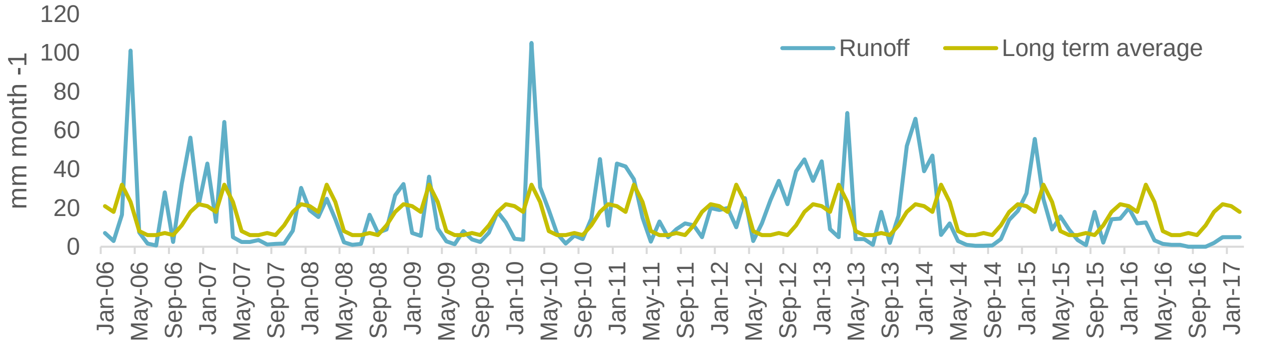

Figure 5. Monthly average runoff in Söderköping, 21 km from Ryttarbacken 2006-2017. Long-term values are calculated by SMHI over a standardized 30 years period

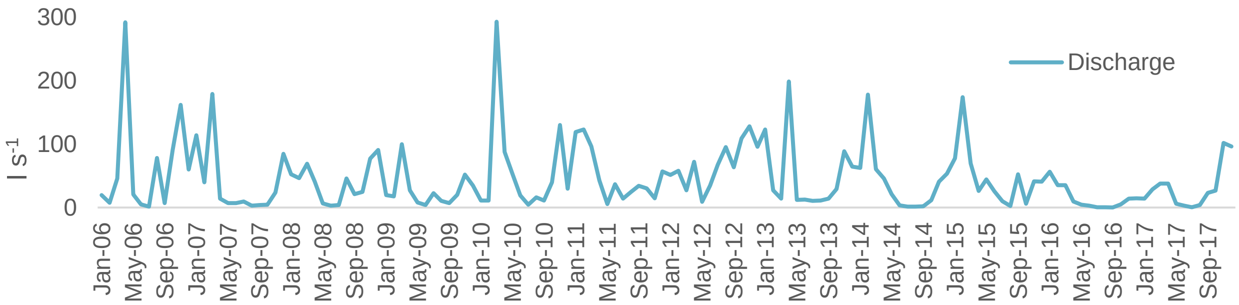

Figure 6. Monthly discharge measured at Ryttarbacken 2006-2017

3 Methods

3.1 Study area

The catchment E23 is located in the north of flat county of Östergötland (Figure 7). The total area of the catchment is 748 ha, where 55% is arable land and 31% consists of forest. The area is moderately hilly and the arable land between the moraine hills consist of heavy clay. The animal husbandry is 0,6 DE/ha of varying animal types (Stjernman Forsberg et al., 2013). The stream is through the catchment is a culvert upstream and an open stream downstream.

The outflow is marked on the map (Figure. 7) at point 69. Point 60 is located near to the road 210 and is the place upstream of the sedimentation pond. The two-stage ditch is between points 53 and 60 and the structure liming is spread through the catchment.

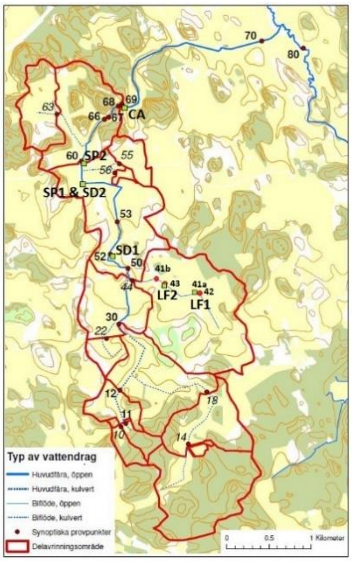

Figure 7. Map of the catchment E23. Sampling point 69 is the catchment outlet and red lines denote the sub catchments

3.2 Data collection

Nutrient data for this study were collected from the database Jordbruksvatten (Agriculture water) from the data host - Agricultural land. The laboratory analyses were done by the Water and Environmental lab at SLU.

Long-term measurements were taken every second week. The measurements started in 1988 as a part of the regional environmental monitoring and had a break between 1995 to 2002. A flow-proportional measurement was installed at the start of FoP in 2007 and are taken as a composite sample every second week when it is enable regarding the water flow.

Synoptic measurements were taken at different sampling points. The main sampling points were 53, 60, 63 and 69 and the water quality was measured during the whole FoP project. Analysed points in this study are all in the main stream. The tributaries have also been measured, but the points' locations have been changing during the project and the raw data consists of just a small number of samples. Therefore, the tributaries are not considered in this study and just the main stream results are shown. After the project finished not so many synoptic measurements have been carried out. The sampling can just be managed during high water flows and when money for analysing the samples is available. 2015, 2016 and 2017 have been the years with less snow and therefore less runoff.

The rate of water flow is measured by the catchments outflow at the same place as the flow proportional measurements. The measuring station is named Ryttarbacken and managed by SMHI. Precipitation data come from the weather station in Söderköping 21 km from Ryttarbacken. The temperature is measured at the weather station in Norrköping, 22 km away from Ryttarbacken. Both stations are managed by SMHI and the data are freely accessible.

3.3 Water quality parameters

Different parameters have been analysed, three fractions of P including total phosphorus (TP), phosphate phosphorus (PO_4-P) and particulate phosphorus (PP). They are the main focus here to see if the mitigations measures have had an effect on water quality.

Other parameters measured include: Nitrogen (N) analyses because of the impact on the environment and nitrate nitrogen (NO_3-N) as contributing the overfertilization. Ammonium nitrogen (NH_4-N) is a waste product of organic nitrogen and has normally very low concentrations since it rapidly nitrifies. In case of oxygen deficiency, ammonium concentrations increase because of non-nitrification (Ekologgruppen, 2014).

TOC, Total organic carbon measures the organic material and describes water quality and the environmental stress. High level of TOC infers lack of oxygen and can cause regional problems with fish and other aquatic organisms (Naturvårdsverket, 2009b).

TSS, total suspended solids are in Sweden, compared to other places not a big environmental problem. The suspended material is still an important carrier of nutrients, especially P. The sedimentation increases during high flows but with less discharge, high concentrations can also depend on small dilution of point sources. It is an important parameter relative to the catchments with clay soils (Djodjic et al., 2012)

3.4 Statistical analyses

Data management and analyses were performed using Excel. For all parameters mean value and standard deviation were calculated.

Long term measurements were divided in two periods. The first period represents the time before FoP (until 2014). The time when the measures took place is 4 years and is in this study included in the first period. The second period represents all available data after 2014.

The nutrient data in the synoptic measurement were divided into two periods 2008-2011 and 2012-2017. It has just been a few measurements in the second group and therefore could not be divided in the same way as the long-term measurements. It would have been interesting to divide the data after when the mitigation measures took place at a specific point but it was not possible because same point were in focus more than one time.

To show the nutrient data, the parameters were explained in different box-plots calculated from the raw data. Boxplot shows the second and third quartile, median value and the maximum and minimum values. To better see the distribution, the axes are cut off not to include maximum values. Maximum values of the samples are written at the top of the box-plot.

The synoptic data were presented in the same way. Some of the datasets were very small and for NH_4-N the samples were not enough to make a boxplot. Even for some of the other parameters, at some points the samples were not enough to do any correct statistical analyses but the analyses were still performed in the same way.

The weather parameters were divided into two groups, same way as the long-term measurements. Weather parameters were analysed to see if the meteorological conditions affect the measures effect. To compare the precipitation and runoff in the long-term measurements, monthly averages were calculated before the measures, Jan 2006- Dec 2014 and after Jan 2015- Dec 2017. As the synoptic nutrient data is divided into 2006-2011 and 2012-2017 both weather divisions are presented in Table 3.

4 Results

4.1 Long-term measurements

Table 2 presents some of the main characteristics of the nutrient data. Data from this table can be compared with the data in Figures 8-15 which show boxplots calculated from that data. Total Phosphorus is lower at point 60 than point 50 and can indicate that two-stage ditch and the sedimentation pond have some effect. Most of the parameters increase downstream. The synoptic data are presented in more detail under section 4.2.

Mean values are higher in the flow-proportional than the manual measurements for all parameters except NH_4-N and TOC. Flow proportional measurements are taken as composite samples and represent the stream better than the manual measurements. Manual measurements have an advantage of the long-time series of data back to 1994 and ability to match concentrations with flow conditions.

Table 2. Mean value, standard deviation and number of samples for the long-term measurements and for the synoptic measurements at all sampling points

	Synoptic			Flow-proportional			Manual		
data parameter mg l^{-1}	**Mean value**	**Standard deviation**	**Number of samples**	**Mean value**	**Standard deviation**	**Number of samples**	**Mean value**	**Standard deviation**	**Number of samples**
TP				0.347	0.168	236	0.261	0.185	721
HE30	0.230	0.157	24						
HE44	0.261	0.135	23						
HE50	0.369	0.433	24						
HE60	0.361	0.216	24						
HE69	0.366	0.270	29						
PO_4-P				0.140	0.130	236	0.140	0.131	41

	Synoptic			Flow-proportional			Manual		
HE30	0.069	0.052	24						
HE44	0.081	0.057	23						
HE50	0.136	0.184	24						
HE60	0.142	0.095	24						
HE69	0.137	0.085	29						
PP				0.146	0.088	236	0.094	0.074	417
HE30	0.124	0.133	23						
HE44	0.150	0.103	22						
HE50	0.191	0.213	23						
HE60	0.202	0.169	20						
HE69	0.214	0.251	24						
TN				4.079	3.605	236	3.931	3.132	721
HE30	5.446	4.788	22						
HE44	5.996	4.691	22						
HE50	6.505	4.409	23						
HE60	6.217	4.136	20						
HE69	5.454	3.543	24						
NO_3-N				3.298	3.445	236	2.539	2.786	721
HE30	4.634	4.446	22						
HE44	5.332	4.856	21						
HE50	5.370	4.084	22						
HE60	5.541	3.749	24						
HE69	4.564	3.194	27						
NH_4-N				0.057	0.149	235	0.231	0.541	721
HE30	0.094	0.197	22						
HE44	0.130	0.398	21						
HE50	0.296	0.749	22						
HE60	0.141	0.251	24						
HE69	0.112	0.158	26						
TOC				13	5	236	13	6	415
HE30	19.398	6.804	22						
HE44	12.326	4.481	21						
HE50	16.441	6.741	22						
HE60	15.022	5.546	19						
HE69	16.524	6.473	23						
TSS				110	100	233	52	75	721
HE30	121.936	123.194	22						
HE44	144.771	117.593	21						
HE50	150.395	146.595	22						
HE60	187.720	222.004	20						

	Synoptic			Flow-proportional	Manual
HE69	195.573	169.591	22		

The manual and flow proportional measurements are presented in the same boxplot. In general, the flow proportional data show a higher concentration of P than the manual. TP and PP show lower concentrations after FoP, even the highest concentrations show a lower value after implementation of the measures (Figure 8 and 9).

Concentrations of TN are higher after FoP and the data variation is higher (Figure 11). This is an unexpected result. Especially NO_3-N has increased but does not stand for the entire N increasing. Organic N is not studied as an own fraction and stand for the rest of the augmentation. NH_4-N shows no major difference in the flow proportional sampling but decreases in the manual measurements. The flow proportional samples show significant lower concentrations of NH_4-N than the manual sampling. Highest values of the NH_4-N are sometimes very high compare to the second and third quartile (Figure 13).

TOC concentrations (Figure 14) are significantly lower after 2015 in the manual measurements. The flow proportional data present a smaller interval but a higher median value. The highest values are lower in both series after implementation of measures.

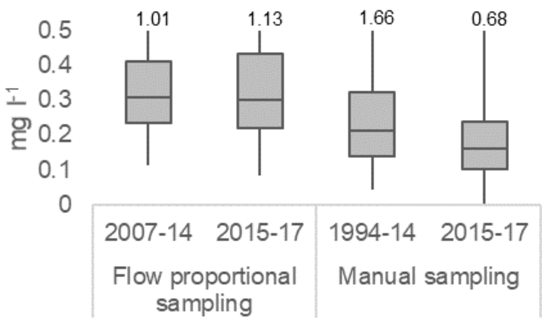

Figure 8. TP concentrations (mg l^{-1}) in flow-proportional and manual measurements until and after 2014 when FoP-project ended

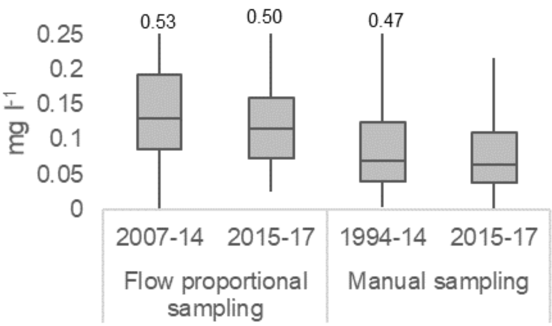

Figure 9. PP concentrations (mg l^{-1}) in flow-proportional and manual measurements until and after 2014 when FoP-project ended

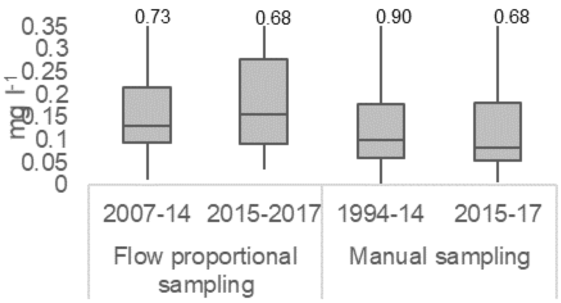

Figure 10. PO_4-P concentrations (mg l^{-1}) in flow-proportional and manual measurements until and after 2014 when FoP-project ended

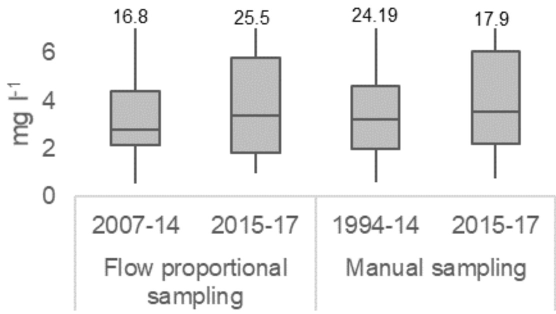

Figure 11. TN concentrations (mg l^{-1}) in flow-proportional and manual measurements until and after 2014 when FoP-project ended

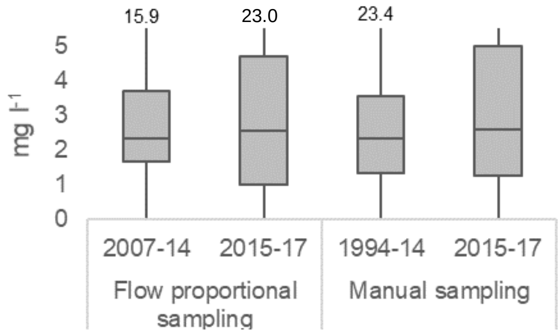

Figure 12. NO_3-N concentrations (mg l^{-1}) in flow-proportional and manual measurements until and after 2014 when FoP-project ended

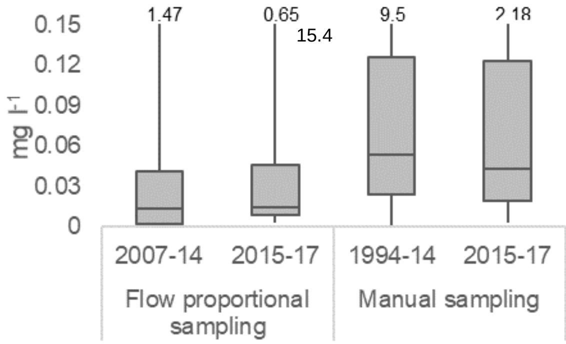

Figure 13. NH_4-N concentrations (mg l^{-1} in flow-proportional and manual measurements until and after 2014 when FoP-project ended

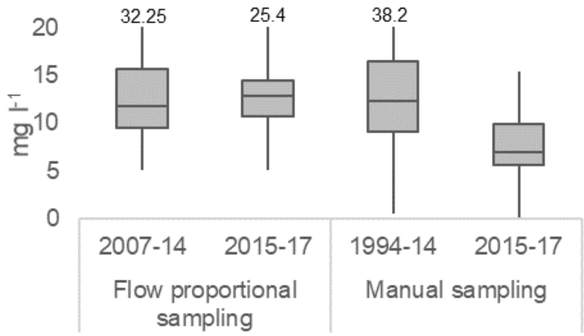

Figure 14. TOC concentrations (mg l^{-1}) in flow-proportional and manual measurements until and after 2014 when FoP-project ended

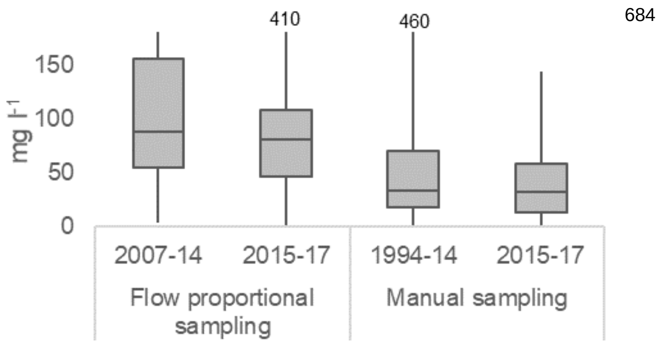

Figure 15. TSS concentrations (mg l^{-1}) in flow-proportional and manual measurements until and after 2014 when FoP-project ended

4.2 Synoptic measurements

Upstream of the point HE30 88 ha of area was structure limed during 2010-2013 and at point HE44 was 50 ha 2010-2012. Point 50 is upstream of the two-stage ditch and where a tributary connects to the main stream. The two-stage ditch and the sedimentation pond are situated upstream of the point 60 and point 69 is located at the catchment outlet.

At all points P concentrations are lower after the implementation of measures (Figures 16, 17 and 18). They all show less distribution and lower highest value. PO_4 -P has after the measures very low concentrations at all points. TN concentrations are at some points, and NO_3-N concentrations at all points higher after the measures. No results for the NH_4-N are shown because data are missing. Any significant differences in TOC in Figure 2, cannot be seen and the concentrations are lower for almost every point after the measures. Concentrations of TSS are reduced at all points. The highest value is significantly lower after the measures. Directly after the construction of the two-stage ditch, the erosion risk was higher so a higher level of TSS directly after construction is not surprising.

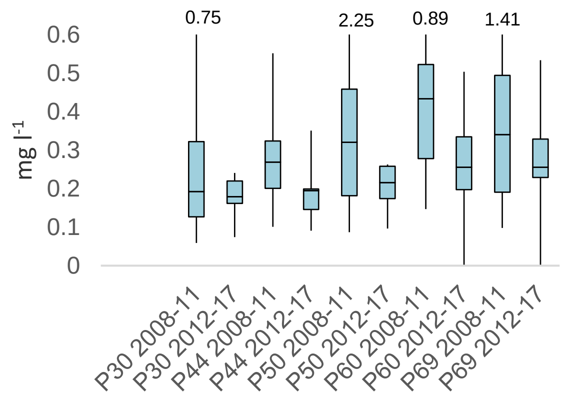

Figure 16. Concentrations of TP before and after measures in E23 at 5 synoptic points in the main stream

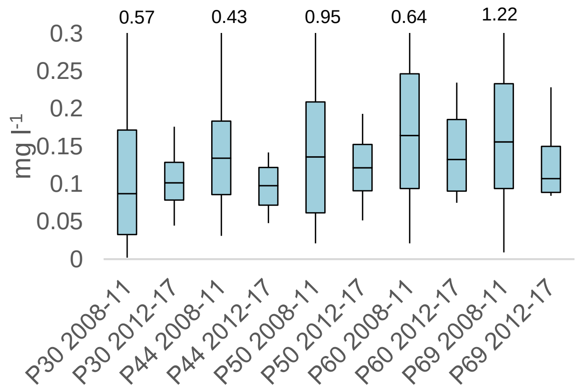

Figure 17. Concentrations of PP before and after measures in E23 at 5 synoptic points in the main stream

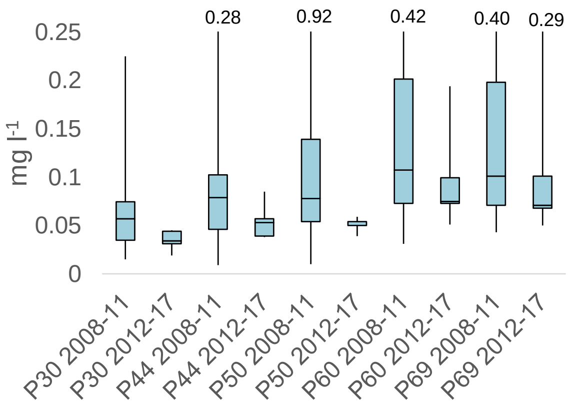

Figure 18. Concentrations of PO_4 -P before and after measures in E23 at 5 synoptic points in the main stream

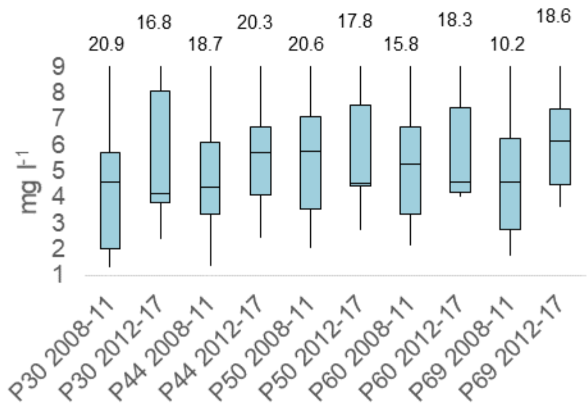

Figure 19. Concentrations of TN before and after measures in E23 at 5 synoptic points in the main stream

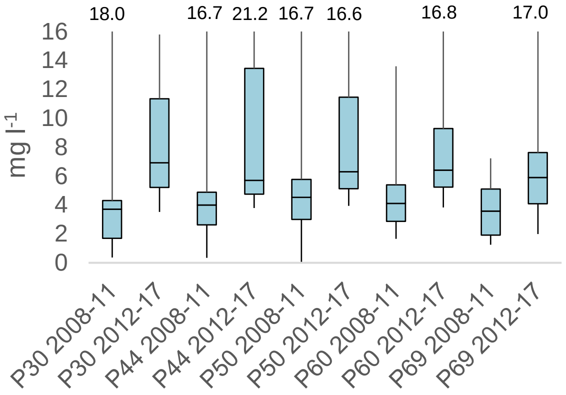

Figure 20. Concentrations of NO_3-N before and after measures in E23 at 5 synoptic points in the main stream

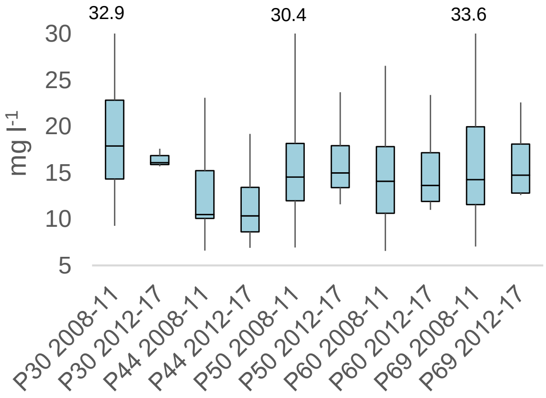

Figure 21. Concentrations of TOC before and after measures in E23 at 5 synoptic points in the main stream

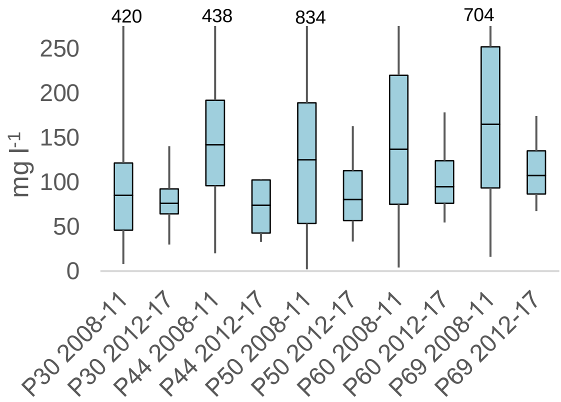

Figure 22. Concentrations of TSS before and after measures in E23 at 5 synoptic points in the main stream

4.3 Weather parameters

Table 3 compares the weather conditions before and after the measures. The temperature shows no major differences before and after the measures while precipitation, runoff and discharge are higher before the measures. Measured temperature is constituently higher than long-term average, run off varies around the long-term average and precipitation is generally a little bit below long-term average.

Table 3. Monthly mean value for weather parameters as the long-term and the synoptic measurements.

	Temperature	**Precipitation**	**Run off**	**Discharge**
	°C	mm	Mm	l/s
Long-term measurements				
2006-2014	7.5	49.0	17.8	48.9
2015-2017	8.3	43.0	9.7	31.3
Synoptic measurements				
2006-2011	7.5	49.2	16.7	47.0
2012-2017	7.9	45.9	15.3	42.0
Long-term average	6.7	49.5	14.8	

5 Discussion

This study analysed the water quality in the catchment E23 by looking at different nutrient concentrations. The aim was to examine if the measures, done in FoP-project had some effect on the water quality.

5.1 Sampling methods

The differences in the different methods are interesting and show the importance of method's choice. The methods have all pros and cons and can illustrate different things. The synoptic measurements are an important tool to see the point source of P leakage in the catchment and the manual sampling has advantage of the long-time series and ability to match the concentrations with flow conditions.

The manual measurements show lower concentrations for all P fractions than the flow proportional. It is because of the manual methods easily can miss the concentration peaks. The variations of nutrient concentrations between methods are bigger for P than N which depends on the nutrients leakage characteristics.

5.2 Effectiveness of the measures

Implemented mitigation measures as two-stage ditch and a sedimentation pond would especially impact PP. The concentrations have decreased but the data are just from two years after the implementation and the effect in a long term is unknown.

TP shows just a small reduction in the flow proportional and manual measurements but a major reduction in the synoptic measurements. PO_4 -P has reduced after the mitigation measures in the long term and decreased to very low concentrations in the synoptic measurements. The structure liming would affect the PO_4 -P and would be the reason to the very low concentrations in the synoptic measurements.

Most interesting are the trends for N. TN increased and this effect is undesirable. NH_4-N did not show any major differences but NO_3-N did. The organic fraction of N is not studied as a separate fraction but is the difference between TN and the other N-fractions. Therefore must also the organic N increase after FoP. This is interesting considering which measures the society will focus on. To work against the eutrophication both N and P are important to be reduced and measures should not counteract each other. The leakage of N can also be affected by the potential changes in crops grown before and after the building of mitigation measures. This would have a larger effect on N leaching, but this effect has not been studied here.

Catch crops and other cropping measures as tillage strategy were also not registered and can have been changing during the last years. N is more sensitive for these type of changes than P. P is instead more sensitive for changes in the meteorological conditions as higher run off and discharge (Ulén et al., 2017).

Concentrations of suspended solids have decreased in all measurements which indicates less erosion. With less erosion PP concentrations are also reduced.

5.3 Impact of weathers conditions

The second question in this study sought to determine how the weather affects the variations of nutrient concentrations. The real impact is hard to evaluate but the results can indicate a connection. The temperature does not show any major differences and would therefore not have a particularly significant impact on the measures effect. Precipitation, runoff and discharge are however higher before than after the measures and therefore would naturally the nutrient concentrations be a little bit lower after the measures.

The nutrient concentrations show in the synoptic data a stronger reduction than in the long-term measurements. It agrees with the weather data, which show larger differences when the data separation takes place in 2012. This may indicate that the meteorological conditions have an impact on the nutrient concentrations. The real impact of varied weather conditions is in this report not studied but the results indicate that it is important. To make further conclusions longer time series after the measures need to be analysed.

The two-stage ditch would better handle more precipitation than a traditional ditch and the last two years had less precipitation and run off than average. The ditch has therefore not shown its full potential and in the future, it will be interesting to see how the nutrient concentrations vary over time. Weather had also a real impact to when it is possible to implement the measures. If the weather conditions are not good enough it is better to wait until a better year. Both the structure liming, two-stage ditch and the sedimentation pond require good weather conditions during construction.

5.4 Potential limitations and other studies

FoP project is the first big project against phosphorus losses in Sweden. Farmers, advisors and scientists worked together to test mitigation methods in practice. When analysing the results, comparison with other studies must be done carefully. Local conditions are important and can have a real impact on the results.

Other studies in North Europe show a reduction of the nutrient concentrations after similar measures. In Southwest Finland, a long term experiment with clay soils concluded that lime-filter ditch, together with buffer zones can reduce both P and TSS (Kirkkala et al., 2011). Research in Lithuania shows that backfilling with burned lime reduced P losses (Saulys and Bastienè, 2008).

Research about two-stage ditches is mainly done in northeast USA. Even if the conditions can be different there compared to Sweden, their research is important to compare Swedish studies with (Johannesson and Kynkäänniemi, 2012).

Measured concentrations can be compared with nutrient concentrations from other clay soils in Sweden. In the Swedish Environmental monitoring program 21 small agricultural catchments are monitored. The catchments differ from each other but the knowledge from one catchment can be used in another (Swedish University of Agricultural Sciences, 2018). Common for all soils in Sweden are that a hundred percent uptake of nutrients is not possible because their natural leaching with more infiltration than evapotranspiration (Eriksson et al., 2011).

This study has a weakness in the number of samples in the synoptic measurements. After the mitigation measures only a few samples have been collected. To do any correct analysis of their effects, more measurements need to be done. The long-term measurements have a lot of raw data and are a better statistical base. Another problem in this study was to connect the weather conditions to the nutrient concentrations in a good way. By dividing the data at the same way as the water quality parameters was it possible to see variations from the long-term average. The time after the measures implemented is too short to do any evaluation about the weather impact.

In future research a correlation between decrease of P and increase of N should be studied. It is important to see if the mitigation measures against P do not increase N concentrations. To analyse the mitigation measures in the future, the cost in relation to the effectiveness needs to be analysed. Some of the measures are costly and to build them at a large scale requires a plan how to fund the measures.

6 Conclusions

This study has shown that some of the measured nutrient concentrations have decreased after the FoP. All fractions of P have decreased which, linked to the project purpose, is desirable. Less desired is the increase of N. Further work needs to be done to establish whether there is any correlation between P reduction and N increase.

The meteorological conditions would affect the concentrations. Time after the measures is just a few years and to make any statistical conclusion more data are needed. A weakness in this study is number of synoptic measurements. To have the opportunity to see if the measures had some effect, both the synoptic and the long-term measurements are needed.

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